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RADIATION PROTECTION SPECIAL STUDY NO. 42-098-75
LASER RANGEFINDER-DESIGNATOR, AN/UAS-9
OCTOBER 1974

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SERVING THE ARMY IN ITS PREVENTIVE MEDICINE PROGRAM

SENTINEL of HEALTH

US ARMY
ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MD 21010

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A special study of the optical radiation hazards of the AN/UAS-9 Laser Rangefinder-Designator (LRFD) was conducted by personnel from the US Army Environmental Hygiene Agency at Sacramento Army Depot on 7 October 1974. It was determined that hazardous levels of optical radiation may exist out to a range of 9.7 km if viewed by the unaided eye.

DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

HSE-RL/WP

31 DEC 1974

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ABSTRACT

A special study of the optical radiation hazards of the AN/UAS-9 Laser Rangefinder-Designator (LRFD) was conducted by personnel from the US Army Environmental Hygiene Agency at Sacramento Army Depot on 7 October 1974. It was determined that hazardous levels of optical radiation may exist out to a range of 9.7 km if viewed by the unaided eye.

It is recommended that unprotected personnel be restricted from the area of the beam path, the guidelines in Appendix B be followed when establishing or using a laser range and the installation surgeon be notified prior to laser operations.

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1. REFERENCES.

a. Paragraph 2-35a(6), AR 10-5, Organization and Functions, Department of the Army, 28 January 1974.

b. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, Department of the Army, 6 February 1974.

c. TB MED 279, Control of Hazards to Health from Laser Radiation, 18 September 1974.

d. Letter, AMXSA-QMD-1, Sacramento Army Depot, 11 October 1974, subject: Request for Laser Evaluation, and indorsement thereto.

2. PURPOSE. To evaluate potential health hazards associated with the use of the AN/UAS-9 Laser Rangefinder-Designator and to make recommendations designed to limit needless exposure of personnel to potentially hazardous radiation from this device.

3. BACKGROUND.

a. General. The AN/UAS-9 laser device was a component part of the Integrated Observation System (IOS), AN/GSQ-184. The complete system was built for the US Marine Corps by RCA Advanced Technology Laboratories at Burlington, MA under contract number DAAB07-73-C-0045. The Integrated Observation System (see Figure 1) consists of a Laser Rangefinder-Designator (LRFD), AN/UAS-9, and an optical equipment mount capable of indicating elevation and azimuth positions.

b. Instrumentation.

(1) EG&G Model 580 Radiometer System with Model 23A Detector Head.

(2) Fish-Schurman ND 419 neutral density filters.

(3) Metascope, Infrared.

c. Abbreviations. A table of commonly used radiometric terms and units is provided in Appendix A.

4. FINDINGS.

a. Laser Output Parameters. The following laser output parameters were measured.

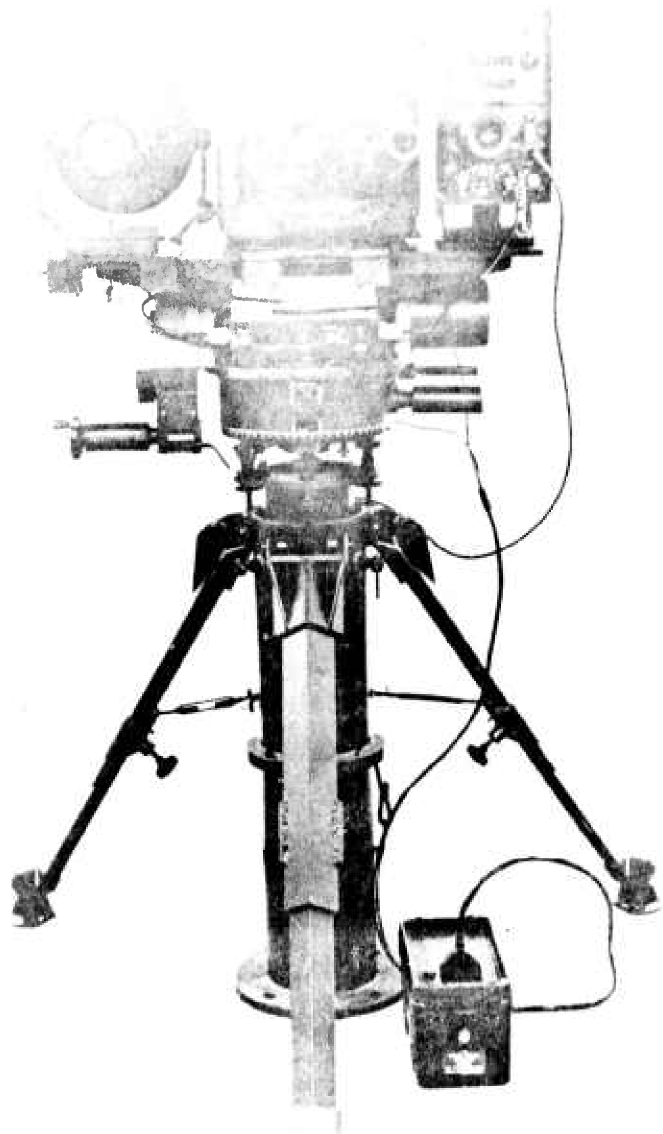

FIGURE 1. INTEGRATED OBSERVATION SYSTEM, AN/GSQ-184. THE LASER RANGEFINDER DESIGNATOR, AN/UAS-9 IS ILLUSTRATED IN THE UPPER RIGHT-HAND PORTION OF THIS PHOTOGRAPH.

(1) Pulse Repetition Frequency: single pulse (rangefinder mode) or 10Hz (designator mode).

(2) Radiant Energy per Pulse: 32 mJ measured (120 mJ specified).

(3) Wavelength: 1,064 nm (Nd: YAG).

(4) Pulse Duration: 20 ns (Q-switched).

(5) Effective Emergent Beam Diameter: 3.1 cm beam diameter at 1/e-peak-radiant-exposure-points (7.5 cm clear aperture measured).

(6) Beam Divergence: 0.47 mrad measured (0.3 mrad specified).

(7) Polarization: $P_{\perp}=0.5$ and $P_{\parallel}=0.5$ (Electric vector pointing upward to the left at approximately a 45° angle while facing the laser).

b. Sighting Telescope. The AN/UAS-9 laser system has a built-in sighting telescope which is boresighted to the laser beam. The telescope provides 10X and 20X selectable magnification. Additionally an attenuating filter with an OD of 2.5 at 1,064 nm was included in the optical train.

c. Beam Characteristics as a Function of Range. Radiometric measurements of beam radiant exposure as a function of range were made on the night of 7 October 1974 at the 500-meter Laser Range at Sacramento Army Depot. Results of these measurements appear in Figure 2. Using equations 8a and 8b of Appendix D, TB MED 279, 18 September 1974, an effective beam divergence of 0.5 mrad was derived. A theoretical plot of radiant exposure versus range also appears in Figure 2.

d. Aiming Accuracy. The system was pointed at a flashlight located at 500 m. Comparing the position of the beam to the position of the flashlight it was determined that the pointing accuracy was slightly larger than 1 mil.

5. DISCUSSION.

a. The Direct Beam. Personnel viewing the direct beam may theoretically receive a corneal radiant exposure/pulse exceeding the single exposure protection standard ($5 \times 10^{-6} J \cdot cm^{-2}$) to a distance of 5.5 km or exceeding the 10 Hz protection standard ($1.6 \times 10^{-6} J \cdot cm^{-2}$) to a distance of 9.7 km. Normally the actual hazardous range would be determined by atmospheric effects or by a natural backstop such as the ground.

b. Specular Reflections. Specular reflections are of greatest concern when the reflecting surface is relatively flat since the reflected beam will remain collimated. Hence, hazardous intensities may be present out to great distances from the surface into possibly uncontrolled areas containing

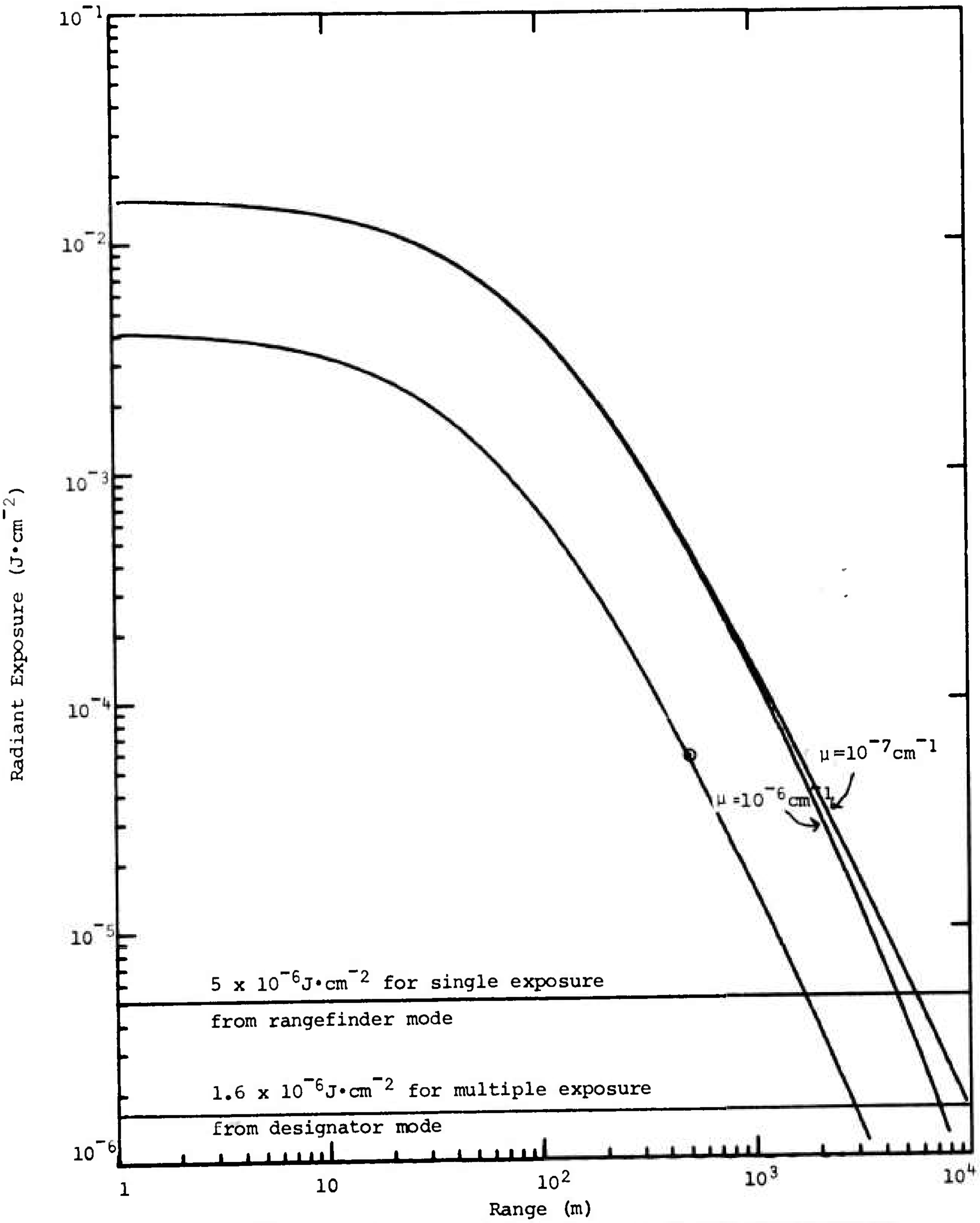

FIGURE 2. BEAM RADIANT EXPOSURE VS. RANGE FOR THE LASER RANGEFINDER-DESIGNATOR, AN/UAS-9. LOWER CURVE REPRESENTS THEORETICAL CURVE FOR MEASURED DATA. UPPER CURVES REPRESENT THEORETICAL CURVES FROM MANUFACTURES SPECIFICATIONS FOR TWO ATMOSPHERIC ATTENUATION COEFFICIENTS, μ.

unprotected personnel. Figures 3 and 4 illustrate the extent of the hazardous envelopes created by the laser beam reflecting from a flat glass surface for two laser beam polarizations. Figure D-1, page 41, TB MED 279, 18 September 1974, provides an indication of the reflectance of glass as a function of incident angle and polarization. (These envelopes assume an 8-percent normal reflection from glass. However, polished metallic surfaces and some dielectric coatings on optics may provide nearly 100-percent reflection. In this situation the hazardous distance from a flat specular surface equals the hazardous range developed for single pulse exposure less the laser-to-target distance.)

c. Diffuse Reflections. The LRFD, AN/UAS-9, does not present a diffuse reflection hazard.

d. Optical Viewing Instruments. The radiant exposure at the retina may be increased by as much as the square of the magnifying power of an optical instrument when viewing either the direct beam or a specularly reflected beam through the optical instrument. [See paragraph c(2) and equations 11-14, Appendix D, TB MED 279, 18 September 1974]. Because of the possibility of individuals with binoculars being located beyond the hazardous range developed for unaided viewers, no single "safe range" appears practical. The point at which the beam is terminated determines the absolute hazardous distance.

e. Eye Protection. Eye protection with a minimum optical density of 5.0 at 1,064 nm would be adequate to protect against intra-beam viewing at any range even if optical instruments were utilized to view the laser. Eye protection with a minimum optical density of 3.9 at 1,064 nm would be adequate to protect against unaided intra-beam or specular-beam viewing.

f. Range Controls. Guidelines for establishing and controlling a laser range are given in Appendix B.

6. CONCLUSION. The LRFD, AN/UAS-9, emits optical radiation exceeding current protection standards. However, this device may be operated safely provided that the operators are informed of the potential hazards and take appropriate precautions.

7. RECOMMENDATIONS.

a. Do not permit unprotected personnel to enter the area of the beam path.

b. Notify the installation surgeon prior to laser operations so that appropriate medical surveillance of maintenance personnel and routine test personnel may be initiated, as outlined in paragraph 5, TB MED 279, 18 September 1974.

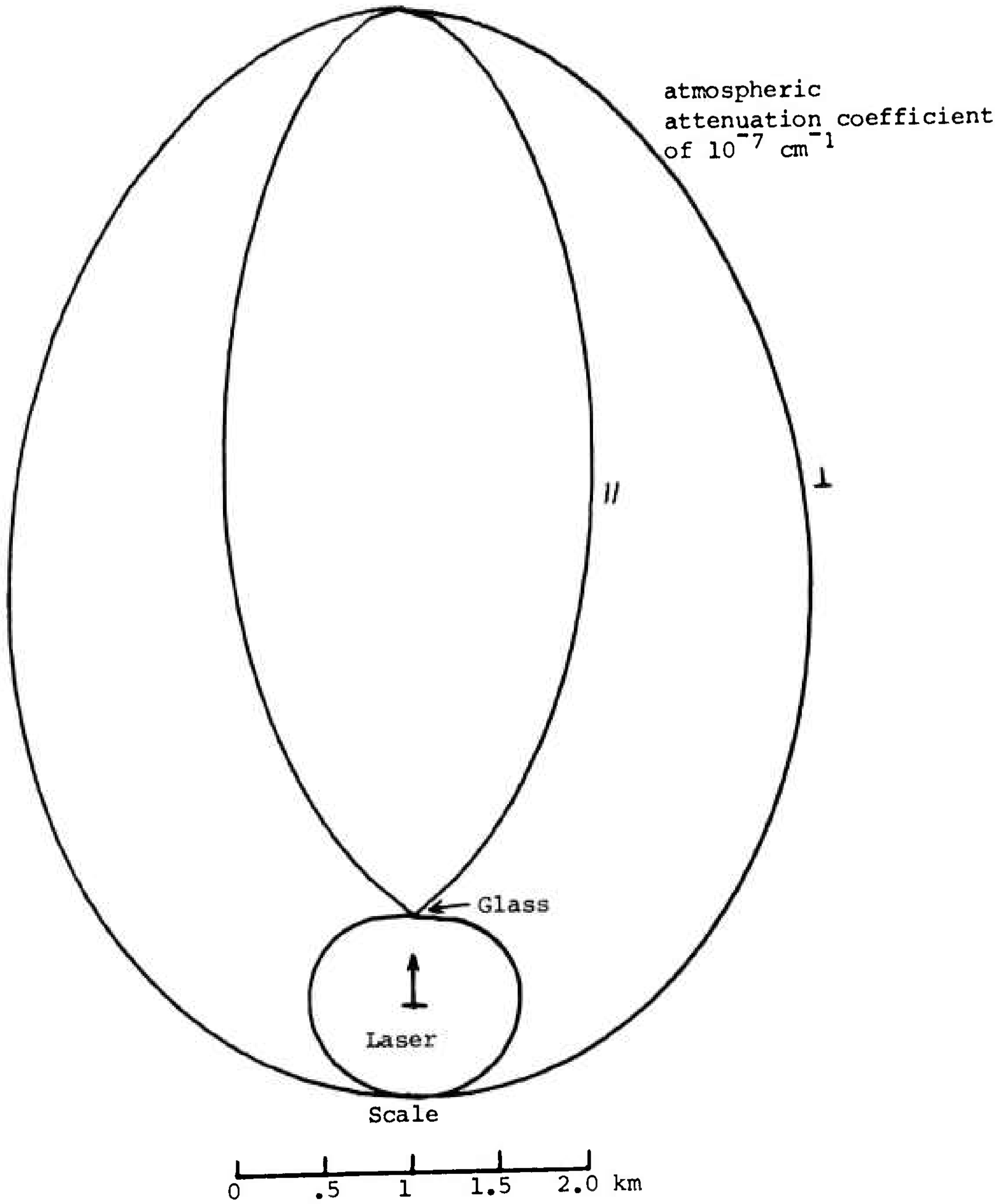

FIGURE 3. HAZARDOUS ENVELOPES CREATED BY SINGLE EXPOSURE TO AIRCREWS FROM SPECULAR REFLECTIONS OF THE AN/UAS-9 LASER BEAM FROM A FLAT GLASS SURFACE. THE GLASS SURFACE IS LOCATED AT 500m FROM THE LASER WITH TWO EXTREME POLARIZATIONS. THE OUTER HAZARD ENVELOPE PROJECTED ON THE GROUND REPRESENTS THE WORST-CASE CONDITION FOR CONSIDERING RESTRICTED AIRSPACE.

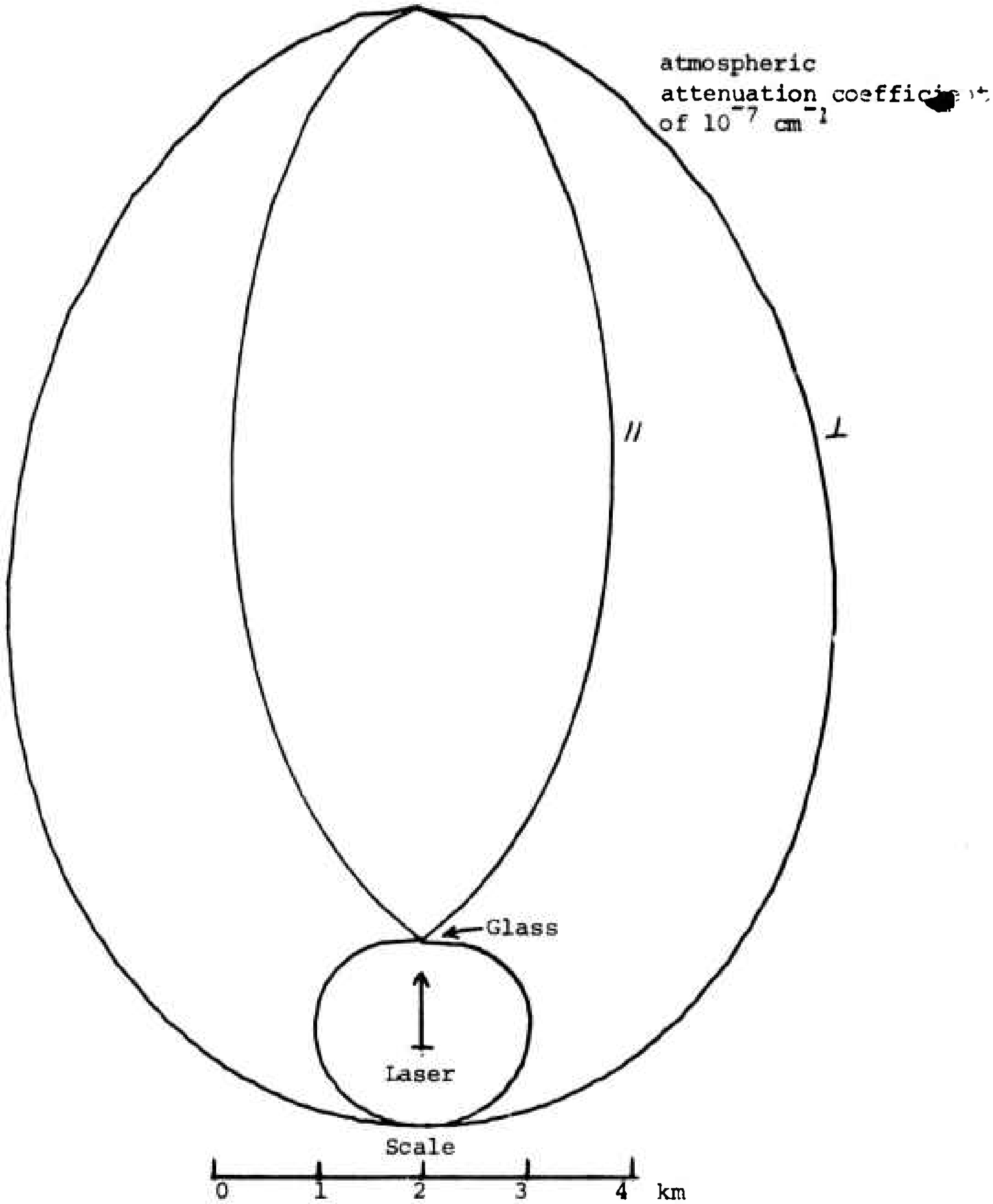

FIGURE 4. HAZARDOUS ENVELOPES CREATED BY MULTIPLE EXPOSURES TO GROUND PERSONNEL FROM SPECULAR REFLECTIONS OF THE AN/UAS-9 LASER BEAM FROM A NEARLY VERTICAL ORIENTED FLAT GLASS SURFACE. THE GLASS SURFACE IS LOCATED AT 1 KM FROM THE LASER WITH TWO EXTREME POLARIZATIONS.

c. The guidelines of Appendix B should be followed when establishing or using a laser range.

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APPENDIX A

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS[1,2]

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	Q_e		Joule (J)	Quantity of Light	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter ($J \cdot m^{-3}$)	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per square meter ($lm \cdot s \cdot m^{-3}$)
Radiant Power (Radiant Flux)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	Φ_v	$\Phi_v = 680 \int \frac{d\Phi_e}{d\lambda} V(\lambda)\, d\lambda$	lumen (lm)
Radiant Exitance	M_e	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cdot \cos\theta \cdot d\Omega$	Watt per square meter ($W \cdot m^{-2}$)	Luminous Exitance	M_v	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cdot \cos\theta \cdot d\Omega$	lumen per square meter $lm \cdot m^{-2}$
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter ($W \cdot m^{-2}$)	Illuminance (luminous flux density)	E_v	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter ($lm \cdot m^{-2}$) lux (lx)
Radiant Intensity	I_e	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian ($W \cdot sr^{-1}$)	Luminous Intensity (candlepower)	I_v	$I_v = \frac{d\Phi_v}{d\Omega}$	lumen per steradian ($lm \cdot sr$) or candela (cd)
Radiance	L_e	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	Watt per steradian and per square meter ($W \cdot sr^{-1} \cdot m^{-2}$)	Luminance	L_v	$L_v = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	candela per square meter ($cd \cdot m^{-1}$)
Radiant Exposure (Dose, in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA}$	Joule per square meter ($J \cdot m^{-2}$)	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt ($lm \cdot W^{-1}$)
				Luminous Efficiency (of a broad band radiation)	V(*)	$V(*) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency [3] (of a source)	η_e	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy[3] (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt ($lm \cdot W^{-1}$)
Optical Density [4]	D_e	$D_e = -\log_{10} \tau_e$	unitless	Optical Density[4]	D_v	$D_v = -\log_{10} \tau_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = \frac{L_v}{S_p}$	troland (td) = luminance in $cd \cdot m^{-2}$ times pupil area in mm^2

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ. For example, spectral irradiance H_λ has units of $W \cdot m^{-2} \cdot m^{-1}$ or more often, $W \cdot cm^{-2} \cdot nm^{-1}$.
2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or μm are most commonly used to express wavelength.
3. P_i is electrical input power in watts.
4. τ is the transmission
5. At the source $L = \frac{dI}{dA \cdot \cos\theta}$ and at a receptor $L = \frac{dE}{d\Omega}$

APPENDIX B

ESTABLISHING RANGES FOR GROUND LOCATED LASER SYSTEMS

1. Scope. The guidance provided deals with range operations in which the laser rangefinder, designator or illuminator is ground located and has a hazardous range of at least 1 km. Because of the varied characteristics of laser systems in use, these guidelines should not be applied to laser systems other than those having a beam divergence of 1° (17 milliradians) or less.

2. Background.

a. The laser system except for its inability to penetrate targets can be treated like a direct-fire, line-of-sight weapon, such as a rifle or machine-gun. Thus, the hazard control precautions taken with respect to those types of weapons will provide most aspects of the safe environment required for laser use. Special control measures for laser use are discussed below.

b. The hazard from these types of laser devices is limited to exposure to the unprotected eye of individuals within the direct laser beam or a laser beam reflected from specular (mirror-like) surfaces. In some cases, however, viewing a diffuse surface reflection is also potentially hazardous. Serious eye damage with permanent impairment of vision can result to unprotected personnel exposed to the laser beam.

c. Essentially, the laser beam travels in a straight line, so it is necessary to provide a backstop, such as a hill behind the target during laser firing (see Figure 5). Calculated nominal hazardous ranges often extend even beyond 8 kilometers, and the use of optical viewing instruments within the beam could extend this hazardous range considerably. For this reason, and because of atmospheric effects upon the beam, the designation of a single "hazardous range" for ground firing range safety purposes is not feasible for most testing and training purposes. The nominal hazardous range may be used in determining the extent of restricted airspace if the beam could be directed or reflected into the air.

d. Every object that the laser beam strikes will reflect some energy back toward the laser. In most cases, this energy is a diffuse reflection and is normally not hazardous, however, certain shiny reflecting surfaces must be avoided as targets to prevent a hazardous amount of radiation from being reflected. These conditions are described in succeeding subparagraphs and illustrated in Figure 6.

3. Laser Range Safety Officer. A person familiar with the range control procedures required for laser operations is termed in this bulletin the "Laser Range Safety Officer" (LRSO). The LRSO is responsible for the following:

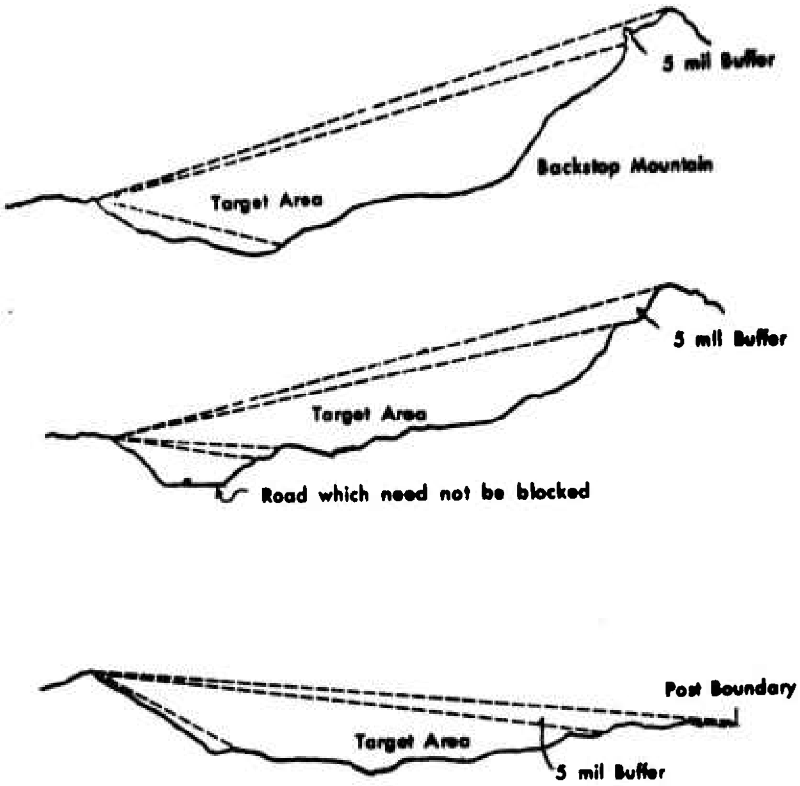

FIGURE 5. EXAMPLES OF THE USE OF BACKSTOPS AND BUFFER ZONES.

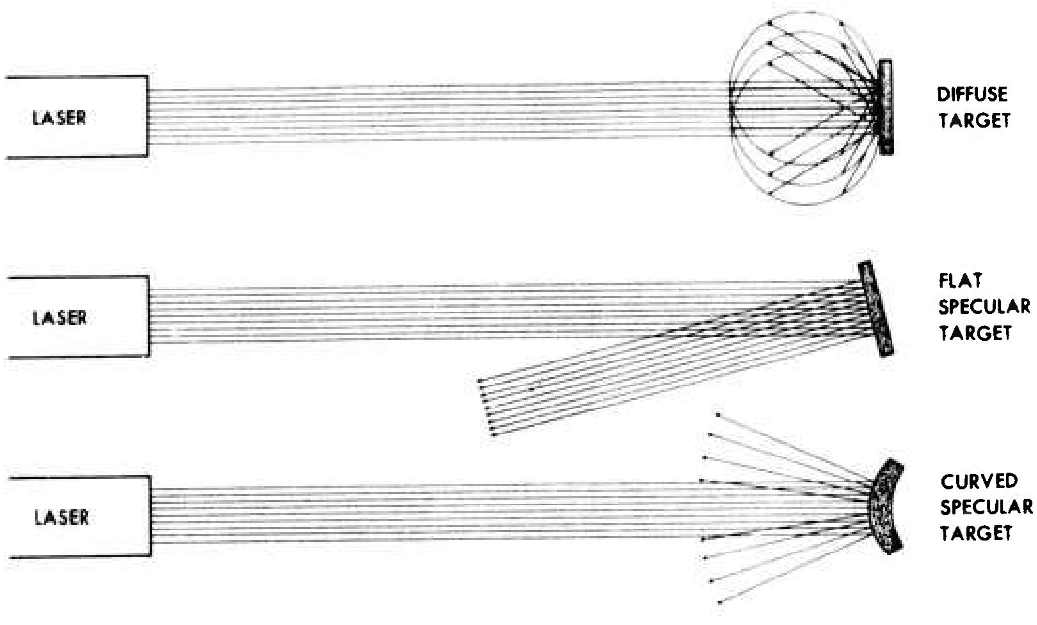

FIGURE 6. REFLECTION PATTERNS FROM DIFFUSE, FLAT SPECULAR, AND CURVED SPECULAR SURFACES.

a. The LRSO will thoroughly instruct all personnel authorized to participate in the laser operation regarding safety precautions to be followed. This instruction should be of such scope as to alleviate any fears generated by a lack of knowledge that may be harbored by participating personnel.

b. The LRSO will insure that safe standing operating procedures are implemented and will establish target areas with the appropriate buffer zones (see paragraph 9) around the target area as defined by the greatest laser-to-target distance. The LRSO will provide adequate surveillance of the target area to insure that no unauthorized personnel enter that area. He will insure that communication with personnel in the target area is maintained to insure that protective eyewear is worn as required during operation. Any break in communication will automatically terminate laser operation.

c. The LRSO is responsible for reporting immediately any case of suspected over-exposure of the eye to laser radiation to the installation surgeon so that an eye examination can be performed within 24 hours of the exposure.

4. Laser Operation. The laser operator will fire only at designated targets which are diffuse reflectors, and will at no time fire at specular surfaces, such as glass, mirrors, windows, etc. This constraint can be met by removing, covering or painting specular surfaces on vehicles.

5. Eye Protection. Those who must be in the target area, such as moving operators or test personnel, shall wear laser protective eyewear with curved protective lenses during laser firing. Such eyewear must be approved for the specific model of laser device being fired. A laser filter designed for protection against one type of laser may not protect against harm from another.

6. Inclement Weather and Night Operations. No precautions other than as previously stated are required at night, or during rain, snow, or fog.

7. Operation Outside of Range Area. The laser system will not be operated or experimented with when removed from its mount unless specifically authorized by the appropriate maintenance manual.

8. Beam Termination. During laser operations no portion of the laser beam will extend beyond the controlled target area. This will be done by construction of the target or choosing a natural target, the size of which will intercept the laser beam and provide an additional buffer zone. Targets will be located in such a manner that they have a geographical backstop, i.e., a mountain or the ground (see Figure 5).

9. Buffer Zone. The extent of the buffer zone depends upon the aiming accuracy of the laser device. The aiming accuracy of the laser device depends upon whether the laser is mounted on a stable platform; i.e., a static base that cannot be easily moved by someone jarring it (e.g., heavy-duty tripod, static tank, reinforced bench mount) or an unstable platform (e.g., light tripod, hand grip, moving tank or aircraft). The static platform generally requires only 2 mil buffer zones; whereas, moving platforms with stabilization generally requires 5 mil buffer zones. For moving platforms without stabilization, 10 mil buffer zones may be required.

10. Optical Instruments. The use of optical devices to observe the target during laser operation will not be permitted unless flat specular surfaces have been removed from the target area or unless appropriate laser safety filters are placed in the optical train of the binocular or telescope.

11. Countdown. A countdown is not required prior to firing in a range environment. The use of range flags during firing serves the purpose of notifying personnel that laser firing or live firing is in progress. Radio communication with personnel downrange in the target area must be provided during laser operation to insure that eye protection is being worn by such personnel.

12. Standing Snow and Water. Hazardous specular reflections from standing snow or water do not present a significant additional hazardous situation to ground personnel and also do not present a hazard to personnel in aircraft outside of the restricted air space above the range.

13. Warning Signs. Evaluation of each anticipated operating condition should include consideration and development of procedures for insuring proper placing of warning signs for that operation. Local standing operating procedures should provide for the placement of temporary or permanent signs during such periods of operation. A sign such as shown in Figure 7 should be used.

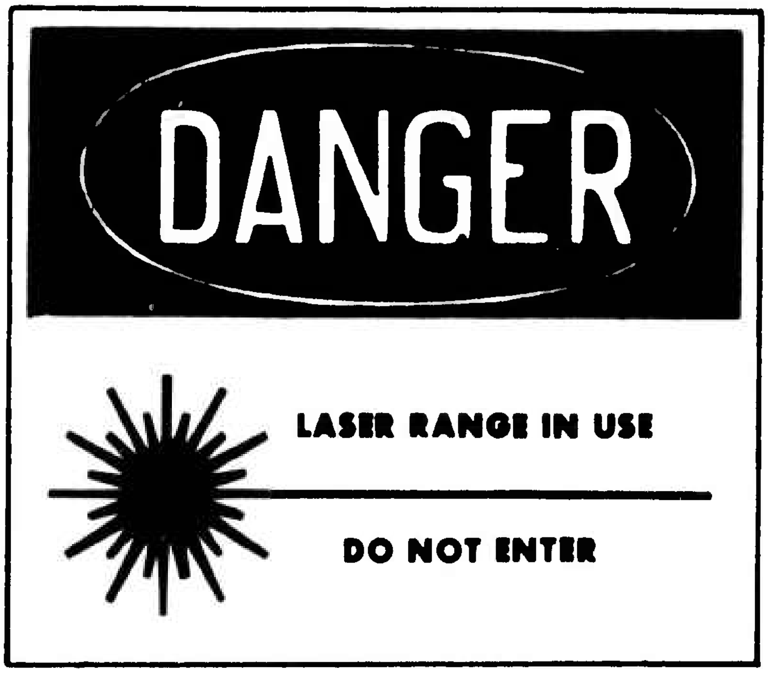

FIGURE 7. SUGGESTED RANGE WARNING SIGN.